

Cyclotron Excitation of the Bernstein Wave in a Spiral Beam-Plasma System

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The cyclotron excitation of the Bernstein wave is observed in a spiral electron beam-plasma system, overlapping on the Cherenkov excitation of the wave. The growth rates of the wave for both excitations are estimated by using the propagating wave pattern in the system.

The electron cyclotron harmonic wave, that is, the Bernstein wave has been investigated by many authors, because it is the most general wave having an interesting characteristic that it appears as a forward and backward waves. It has been reported in the previous paper,^{1),2)} that, in the electron beam-plasma system, the convective and absolute instabilities occur corresponding to the forward and backward waves with respect to the propagation component along the field.³⁾ These instabilities refer to the Cherenkov excitation of the wave, which results from the coupling of the wave with the slow space charge wave of beam. The experimental results are consistently explained by the dispersion relation of the wave in a warm plasma penetrated by the straight electron beam.⁴⁾ Another excitation of the wave, that is, the cyclotron excitation has not been observed in the straight beam-plasma system, because of the much smaller growth rate of this excitation.⁴⁾ In this letter, we report that the latter excitation is observed in a spiral electron beam-plasma system, overlapping on the former one.

The plasma is produced by the dc discharge in the TP-D type device⁵⁾ and diffused along the line of magnetic force into the chamber (9.5cm in diameter and 65cm in length), its parameters being as follows. The density $n_p=3.5-5.3 \times 10^9 \text{ cm}^{-3}$, the electron temperature $T_e=7.0 \text{ eV}$, the magnetic field $B=60 \text{ gauss}$ (homogeneity $<3\%$) corresponding to the electron cyclotron frequency $\omega_c/2\pi=168 \text{ MHz}$, the plasma diameter $D=30\text{mm}$ and the pressure of the neutrals (Ar) $p=7.4 \times 10^{-4} \text{ torr}$ (the collision frequency of electron with neutrals $\nu_{en}=4 \text{ MHz}$ is much smaller than $\omega_c/2\pi$). The electron beam is generated by an electron gun placed at the opposite side of the discharge region and injected into the diffused plasma, so that the electron beam-plasma system is formed and the density n_b and velocity v_0 (or energy V_0) of

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the beam are controlled independently on the plasma parameters. Moreover, the ratio of the velocity component $v_{o\perp}$ of beam perpendicular to the magnetic field to the parallel one $v_{o\parallel}$ can be varied continuously by varying the beam injection

angle θ with respect to the line of magnetic force.

The test wave is excited by the coaxial antenna situated in the center of plasma ($r=0$ and $z=0$) and detected by the other antenna movable axially. By using the interferometer system, the propagating wave patterns along the field (along the axial direction z) are observed. The lower pattern (a) of Fig.1 shows the wave propagation along the field in a straight electron beam-plasma system. It is seen that a single wave whose wave number k_{\parallel} satisfies the Cherenkov excitation condition $\omega=k_{\parallel} v_{o\parallel}$, is amplified along the direction of streaming of electron beam. This result is the same as that of the previous papers.^{1),2)} When the perpendicular velocity component $v_{o\perp}$ (or perpendicular energy component $V_{o\perp}$) is increased by increasing θ , a clear amplification pattern of single wave is no longer observed but the amplitude is modulated at smaller wave number Δk_{\parallel} , the feature of which is shown in Fig.1. Comparing both patterns in the figure, another wave excitation mechanism is expected to occur in the upper pattern, in addition to the Cherenkov excitation

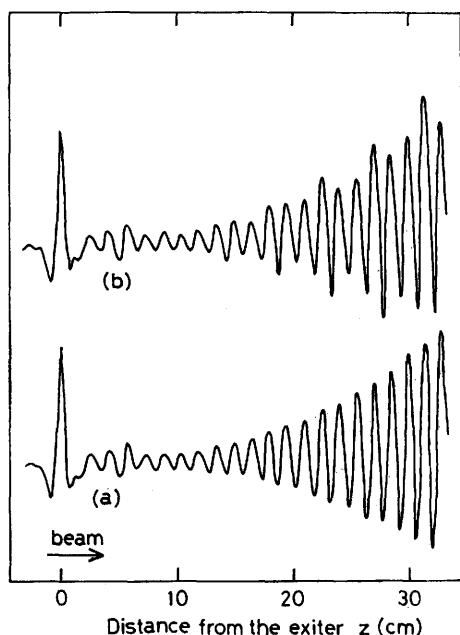


Fig. 1 Propagating pattern of the test wave excited by a coaxial antenna in a beam-plasma system. $\omega_c/2\pi=168$ MHz. $\omega/2\pi=470$ MHz. The lower pattern (a) : in the straight electron beam-plasma system, that is, $V_{o\perp}=0$ eV. and $V_{o\parallel}=135$ eV. The upper pattern (b) : in the spiral electron beam-plasma system, that is, $V_{o\perp}=45$ eV and $V_{o\parallel}=135$ eV. The beam current $I_o=1.5$ mA. The normalized plasma density $(\omega_p/\omega_c)^2=8.3$.

seen in the lower one.

In order to analyse the former pattern, we may describe the growth of the wave satisfying the Cherenkov excitation condition and the modulation of amplitude increasing with distance z as $\exp(\alpha_1 z) + \exp(\alpha_2 z) \exp(j \Delta k_{\parallel} z)$, so that the pattern is expressed approximately as follows,

$$\phi \sim \exp(j k_{\parallel}^{(1)} z) (\exp(\alpha_1 z) + \exp(\alpha_2 z) \exp(j \Delta k_{\parallel} z)) = \exp(\alpha_1 + j k_{\parallel}^{(1)}) z + \exp(\alpha_2 + j k_{\parallel}^{(2)}) z, \\ k_{\parallel}^{(2)} = k_{\parallel}^{(1)} + \Delta k_{\parallel}. \quad \dots\dots\dots(1)$$

α_1 and $k_{\parallel}^{(1)}$ are the growth rate and wave number of the wave resulted from the Cherenkov excitation, which are determined by the lower pattern(a). α_2 and Δk_{\parallel} are 'growth rate' and 'wave number' of the modulation of amplitude seen in the upper

pattern(b). Eq.(1) shows that the upper pattern involve two growing waves whose growth rates and wave numbers are $(\alpha_1, k_{\parallel}^{(1)})$ and $(\alpha_2, k_{\parallel}^{(2)})$, respectively.

The same measurements are done for several frequencies, and the values of

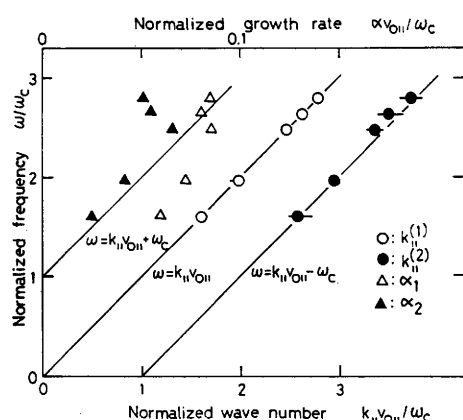


Fig. 2 The wave numbers $k_{\parallel}^{(1)}$ and $k_{\parallel}^{(2)}$ and the growth rates α_1 and α_2 as functions of the frequency of excited test wave. $\omega_c/2\pi = 168$ MHz, $V_{o\perp} = 45$ eV, $V_{o\parallel} = 135$ eV, $I_o = 1.5$ mA, $(\omega_p/\omega_c)^2 = 8.3$.

$\alpha_1, k_{\parallel}^{(1)}, \alpha_2$ and $k_{\parallel}^{(2)}$ are determined, following the above consideration. The results are shown in Fig.2. Values of $k_{\parallel}^{(1)}$ and $k_{\parallel}^{(2)}$ satisfy the relations $\omega = k_{\parallel}^{(1)} v_{o\parallel}$ and $\omega = k_{\parallel}^{(2)} v_{o\parallel} - \omega_c$, respectively. The latter relation is the cyclotron excitation condition. Therefore, it is concluded that in the *spiral* electron beam-plasma system ($v_{o\perp} \neq 0$), the cyclotron excitation of the Bernstein wave is observed, overlapping on the Cherenkov excitation, and the growth rate of the former is too large to be comparable with that of the latter, while in the *straight* electron beam-plasma system, the former can be never observed but only the latter is done. The results are consistent with the theoretical consideration⁴⁾, where the growth rate of

the former is much smaller than that of the latter in the straight electron beam-plasma system.

References

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